

International Earth Science Constellation Mission Operations Working Group

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Aqua/Aura Spring 2017 Inclination Adjust Maneuver Series

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Agenda

- Recap Aqua/Aura 2017 Inclination Adjust Maneuver (IAM) Campaign
 - Maneuver Results
 - Mid-Series Planning Update
 - Aura Trending Model Update
- 2018 IAM Campaign Dates and Planning
- Aqua/Aura Latest Lifetime Mean Local Time (MLT) Term Predictions

Aqua/Aura Spring 2017 Series Summary

- Aqua performed four inclination maneuvers between March 1st and March 29th
- Aura performed four inclination maneuvers between March 2nd and March 30th
- Aqua's third inclination maneuver was re-planned based on the results and performance differences between the first two inclination maneuvers. The fourth and final inclination maneuver was re-planned based on the results from the third inclination maneuver
- Aura's final two inclination maneuvers were likewise re-planned to maintain the phasing with Aqua requirement
- Aqua's inclination maneuvers were between 0.1% and 1.3% cold
- Aura's inclination maneuvers were between 2% and 3% cold

Note: A characteristic of Aqua and Aura inclination (INC) maneuvers includes small changes in semi-major axis (SMA) and right ascension of the ascending node (RAAN). More details on these changes in the following performance slides

Aqua Initial Plan and Actual Performance

Initial Plan

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
52	March 1, 2017	-86.50	550.00	1.1087	13.65	-0.00825	0.00142
53	March 8, 2017	-86.50	550.00	1.2670	11.12	-0.00817	0.00098
54	March 22, 2017	-86.50	550.00	1.3009	-105.00	-0.00840	0.00053
55	March 29, 2017	-86.50	550.00	1.2844	-99.10	-0.00810	0.00007
					Totals:	-0.03292	0.00300

Actual Performance

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
52	March 1, 2017	-87.30	550.00	1.2818	18.85	-0.00817	0.00119
53	March 8, 2017	-87.30	550.00	1.2758	52.30	-0.00816	0.00079
54	March 22, 2017	-90.30 [†]	550.00	1.3021	-23.75	-0.00829	-0.00009
55	March 29, 2017	-92.50 ^{††}	550.00	1.2875	-107.90	-0.00809	-0.00045
					Totals:	-0.03271	0.00144
					Diff from Orig.	-0.64%	

[†] Yaw angle adjusted due to large difference in achieved delta-Semimajor Axis (delta-SMA) between IAM 52 and 53. The IAM 54 yaw angle increased to maintain ground track error (GTE) within required bounds.

^{††} Yaw angle increased again to achieve a more negative delta-SMA and maintain GTE within required bounds.

Aura Initial Plan and Actual Performance

Initial Plan

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
49	March 2, 2017	-83.80	405.00	1.3233	13.10	-0.00893	0.00174
50	March 9, 2017	-83.80	405.00	1.3271	20.10	-0.00900	0.00125
51	March 23, 2017	-83.80	405.00	1.3431	15.80	-0.00921	0.00074
52	March 30, 2017	-83.80	405.00	1.3531	-9.10	-0.00925	0.00023
					Totals:	-0.03640	0.00396

Actual Performance

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
49	March 2, 2017	-83.80	395.00	1.2958	14.10	-0.00872	0.00119
50	March 9, 2017	-83.80	395.00	1.2828	8.60	-0.00875	0.00079
51	March 23, 2017	-83.80	405.00	1.3135	1.00	-0.00899	-0.00001
52	March 30, 2017	-84.50 [†]	410.00	1.3189	-23.50	-0.00905	-0.00045
					Totals:	-0.03551	0.00143
					Diff from Orig.	-2.51%	

[†] Yaw angle adjusted to accommodate a 4.75 sec risk mitigation maneuver (RMM) executed on 26-Mar-2017 11:10:00 UTC.

Aura Trending Model Update

- Aura inclination maneuvers were consistently between 2% and 3% COLD
- Analysis will be performed in the upcoming months to adjust the trending model used in predicting the Aura IAM maneuver performance to reduce this error
- A similar analysis with Aqua approximately two years ago yielded improved maneuver performance

Planned vs. Actual Delta Inclination

IAM #	Date	Planned Delta-V (m/sec)	Actual Delta-V (m/sec)	Planned Delta-Inc (deg)	Actual Delta-Inc (deg)	Difference (deg)	% Difference
49	March 2, 2017	1.3233	1.2958	-0.00893	-0.00872	0.00021	-2.44%
50	March 9, 2017	1.3271	1.2828	-0.00900	-0.00875	0.00025	-2.86%
51	March 23, 2017	1.3431	1.3135	-0.00921	-0.00899	0.00022	-2.45%
52	March 30, 2017	1.3531	1.3189	-0.00925	-0.00905	0.00020	-2.15%
					Totals:	0.00088	-2.51%

Post-IAM Series Drag Make-up Maneuver Strategy

- Aqua and Aura continue to perform no-slew drag make-up (DMU) maneuvers using the mirror pole strategy
- They operate using a hybrid maneuver scheme
 - DMU maneuvers are nominally performed at alternating pole locations
 - RMM locations are dictated by conjunction timing and geometry
 - One (or more) frozen orbit maneuvers are added per year (near the end of the calendar year) to maintain frozen orbit requirements
 - DMU maneuvers performed near the start of the IAM series are planned so that they adjust the control box location in preparation for the IAMs
- With the current low-drag environment, they are using a modified targeting scheme now:
 - A four week DMU tempo is being utilized for maneuver planning
 - GTE controlled near the top of the control box
 - Allows room to execute RMMs and remain in the control box

AQUA

Post IAM Series Aqua/Aura DMUs to Date

DMU #	DMU Maneuver Type	Date
117	No-Slew Mirror Pole – North	April 13, 2017
118	No-Slew Mirror Pole – South	May 10, 2017

AURA

DMU #	DMU Maneuver Type	Date
102	No-Slew Mirror Pole – South	May 3, 2017

Aqua Spring 2018 IAM Campaign Planning

- The Aqua Spring 2018 IAM plan consists of five inclination maneuvers
- Proposed plan has four maneuvers occurring before the ideal burn date and one after
 - March 7, 2018 (IAM #56)
 - March 14, 2018 (IAM #57)
 - March 21, 2018 (IAM #58)
 - March 28, 2018 (IAM #59)
 - April 4, 2018 (IAM #60)
- Aqua's predicted ideal burn date occurs around March 31, 2018

Note: Performing maneuvers off of the ideal date slightly decreases burn efficiency

Aura Spring 2018 IAM Campaign Planning

- The Aura Spring 2018 IAM plan consists of five inclination maneuvers
- Proposed plan has three maneuvers occurring before the ideal burn date and two after
 - March 8, 2018 (IAM #53)
 - March 15, 2018 (IAM #54)
 - March 22, 2018 (IAM #55)
 - March 29, 2018 (IAM #56)
 - April 5, 2018 (IAM #57)
- Aura's predicted ideal burn date occurs around March 27, 2018

Note: Performing maneuvers off of the ideal date slightly decreases burn efficiency

Proposed Aqua/Aura 2018 Maneuver Schedule

Aqua/Aura 2018 Inclination Maneuver Series Schedule

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				March 1	2	3
4	5	6	7 Aqua IAM#56	8 Aura IAM#53	9	10
11	12	13	14 Aqua IAM#57	15 Aura IAM#54	16	17
18	19	20 Equinox	21 Aqua IAM#58	22 Aura IAM#55	23	24
25	26	27 Aura Ideal Date	28 Aqua IAM#59	29 Aura IAM#56	30	31 Aqua Ideal Date
April 1 Easter Sunday	2	3	4 Aqua IAM#60	5 Aura IAM#57	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21*

*Japan Golden Week starts April 29

AQUA

2018 Predicted Maneuver Performance

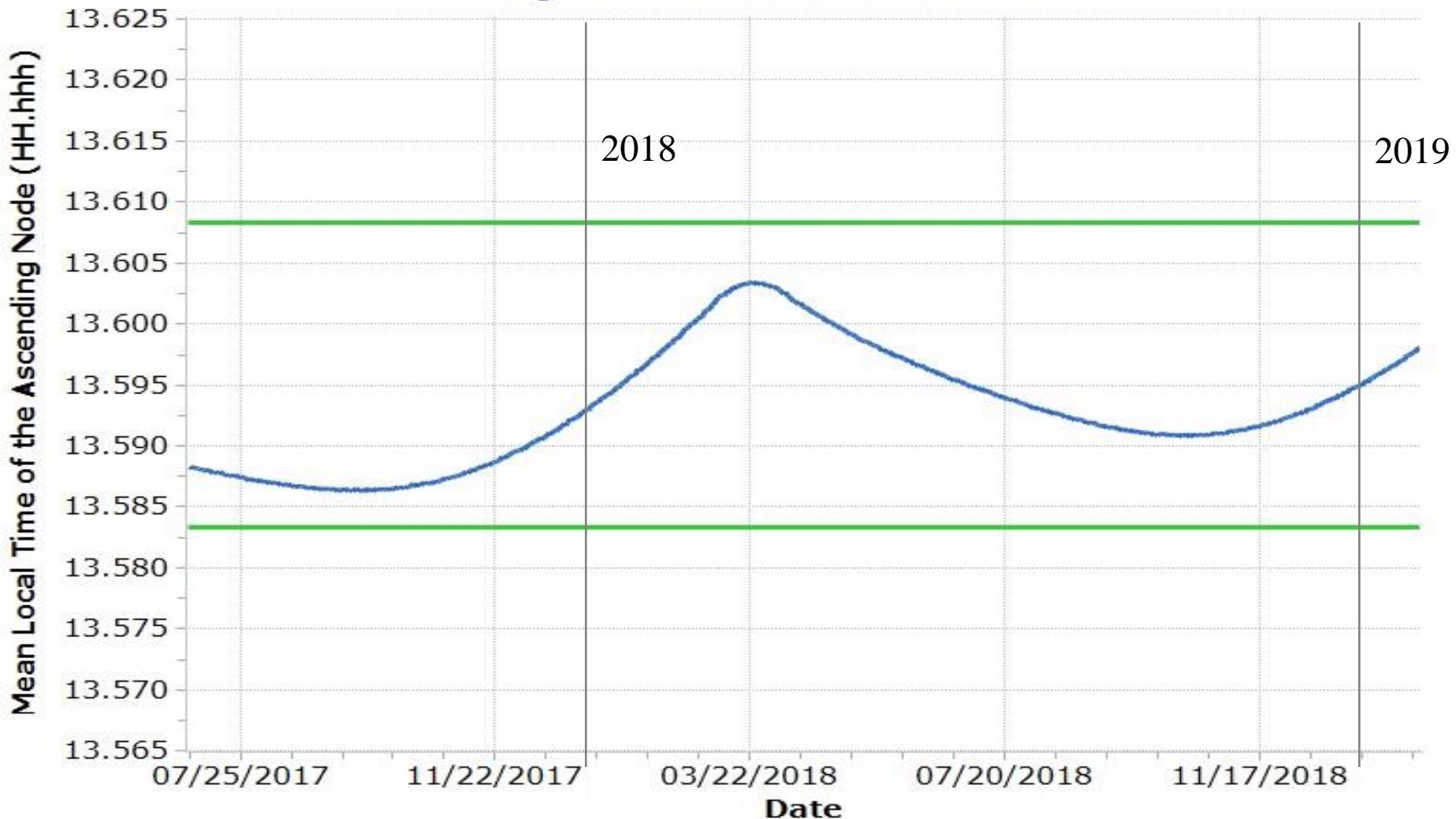
IAM #	Date	Commanded Yaw Angle (deg)*	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
56	March 7, 2018	-87.20	550.00	1.27596	0.16	-0.00823	0.00103
57	March 14, 2018	-87.20	550.00	1.27043	3.85	-0.00823	0.00058
58	March 21, 2018	-87.20	550.00	1.26496	7.51	-0.00820	0.00014
59	March 28, 2018	-87.20	550.00	1.25954	11.14	-0.00815	-0.00029
60	April 4, 2018	-87.20	550.00	1.25417	14.75	-0.00808	-0.00072
		* Preliminary angles			Total Delta-Inc (deg)	-0.04089	0.00074

IAM #	Date	Commanded Yaw Angle (deg)*	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
53	March 8, 2018	-84.20	385.50	1.14309	6.11	-0.00861	0.00134
54	March 15, 2018	-84.70	385.00	1.13775	-7.98	-0.00861	0.00088
55	March 22, 2018	-84.70	385.50	1.13484	-8.13	-0.00863	0.00039
56	March 29, 2018	-84.70	385.50	1.13072	-8.18	-0.00861	-0.00008
57	April 5, 2018	-84.70	385.50	1.12756	-8.03	-0.00857	-0.00053
		* Preliminary angles			Total Delta-Inc (deg)	-0.04303	0.00199

* Source: Lifetime Results, Draft Aqua Decommissioning Analysis, 30-Jun-2016, Juan Ojedo Romero and Waqar Zaidi

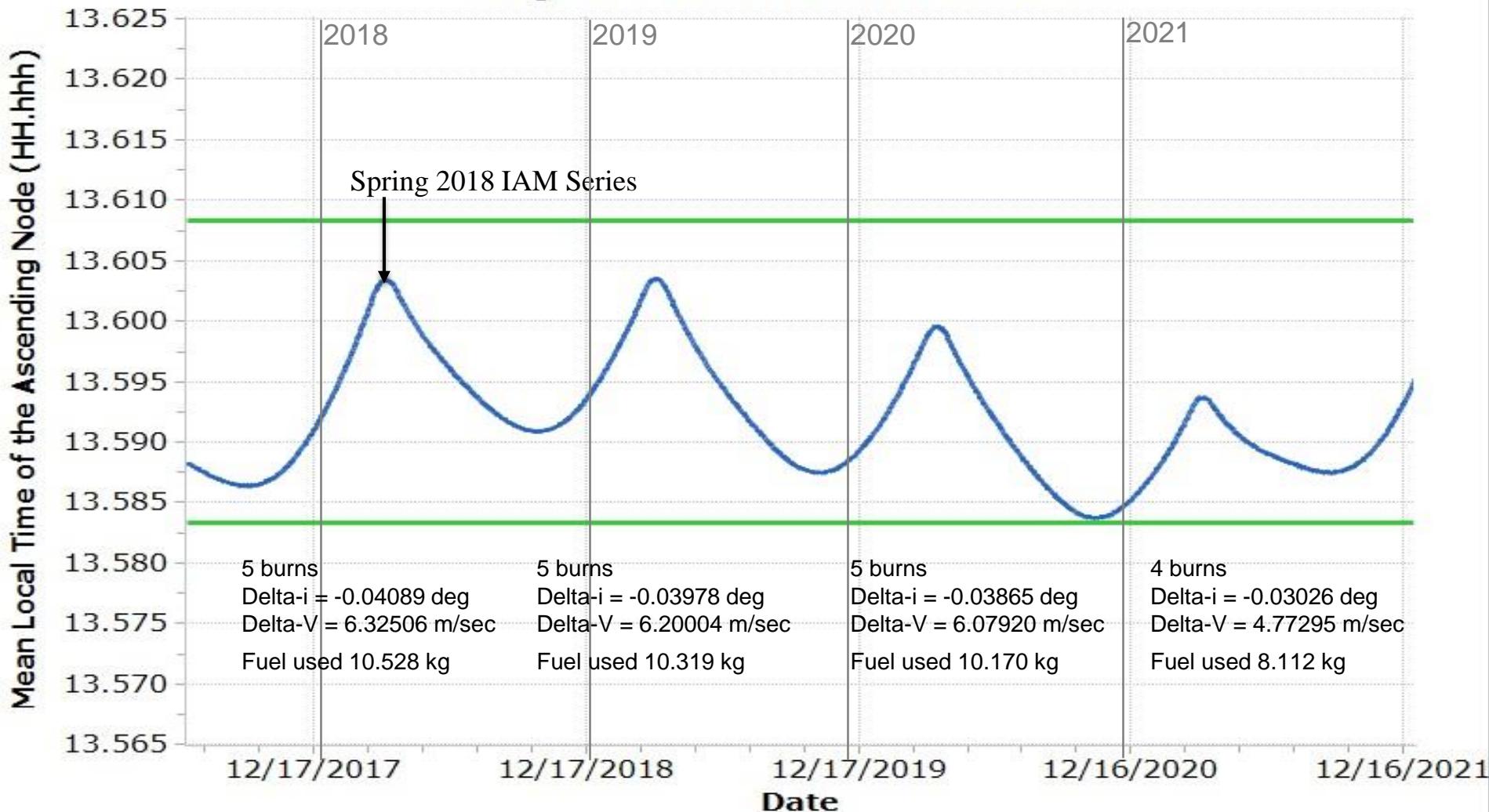
Aqua Predicted Pre- and Post-2018 IAM MLT

Aqua Mean Local Time



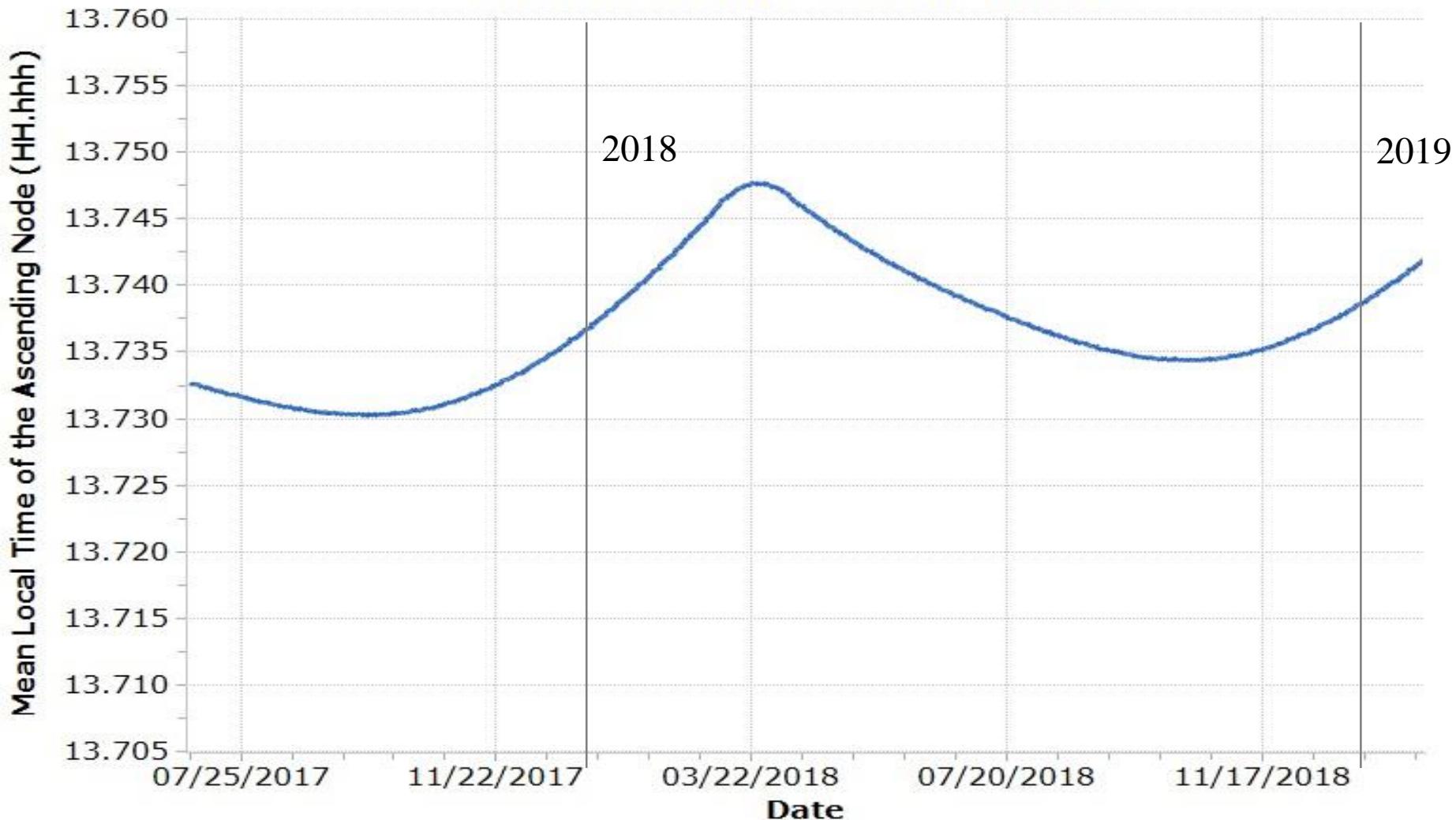
Aqua Lifetime MLT Based on Planned IAM Strategy

Aqua Mean Local Time



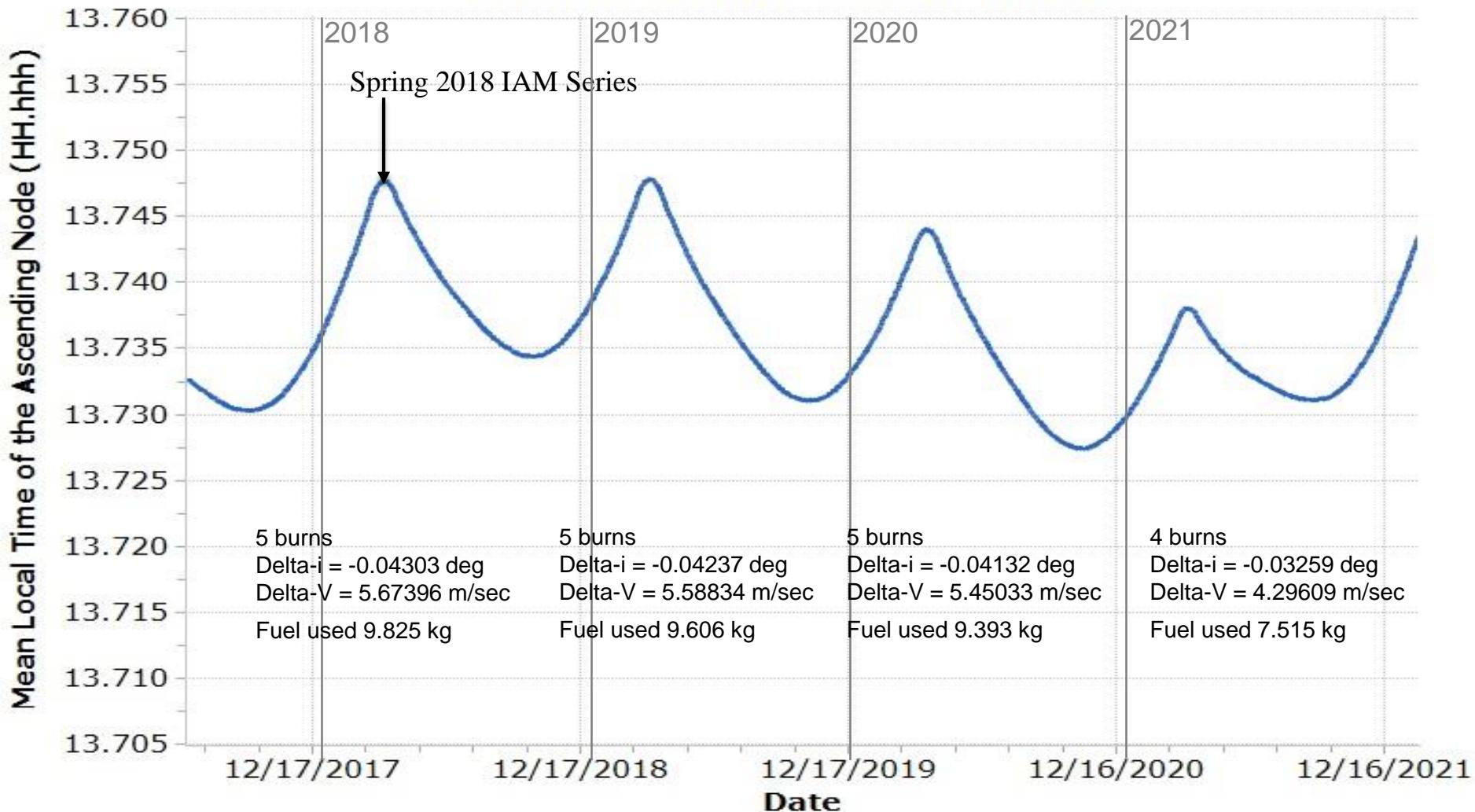
Aura Predicted Pre- and Post-2018 IAM MLT

Aura Mean Local Time



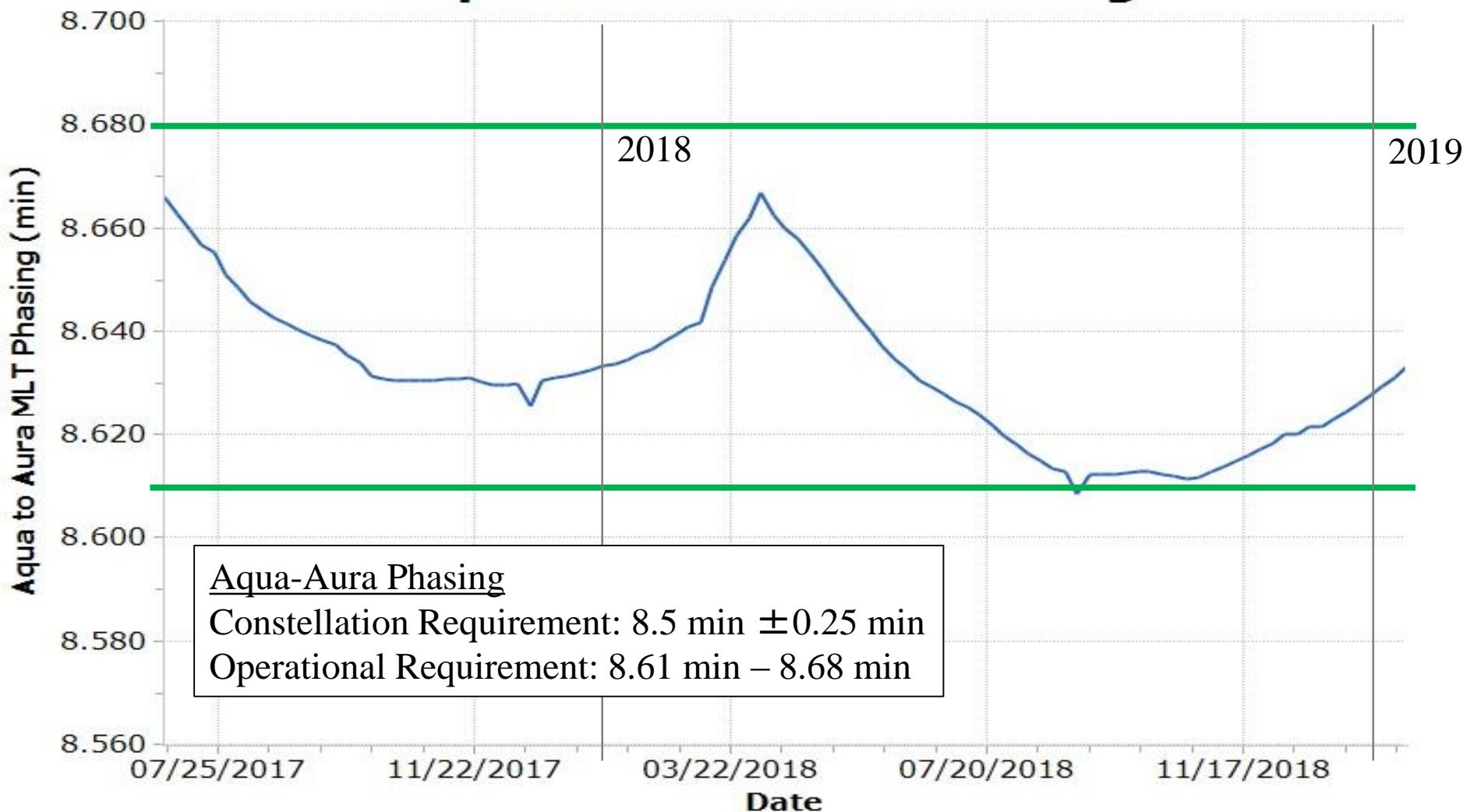
Aura Lifetime MLT Based on Planned IAM Strategy

Aura Mean Local Time



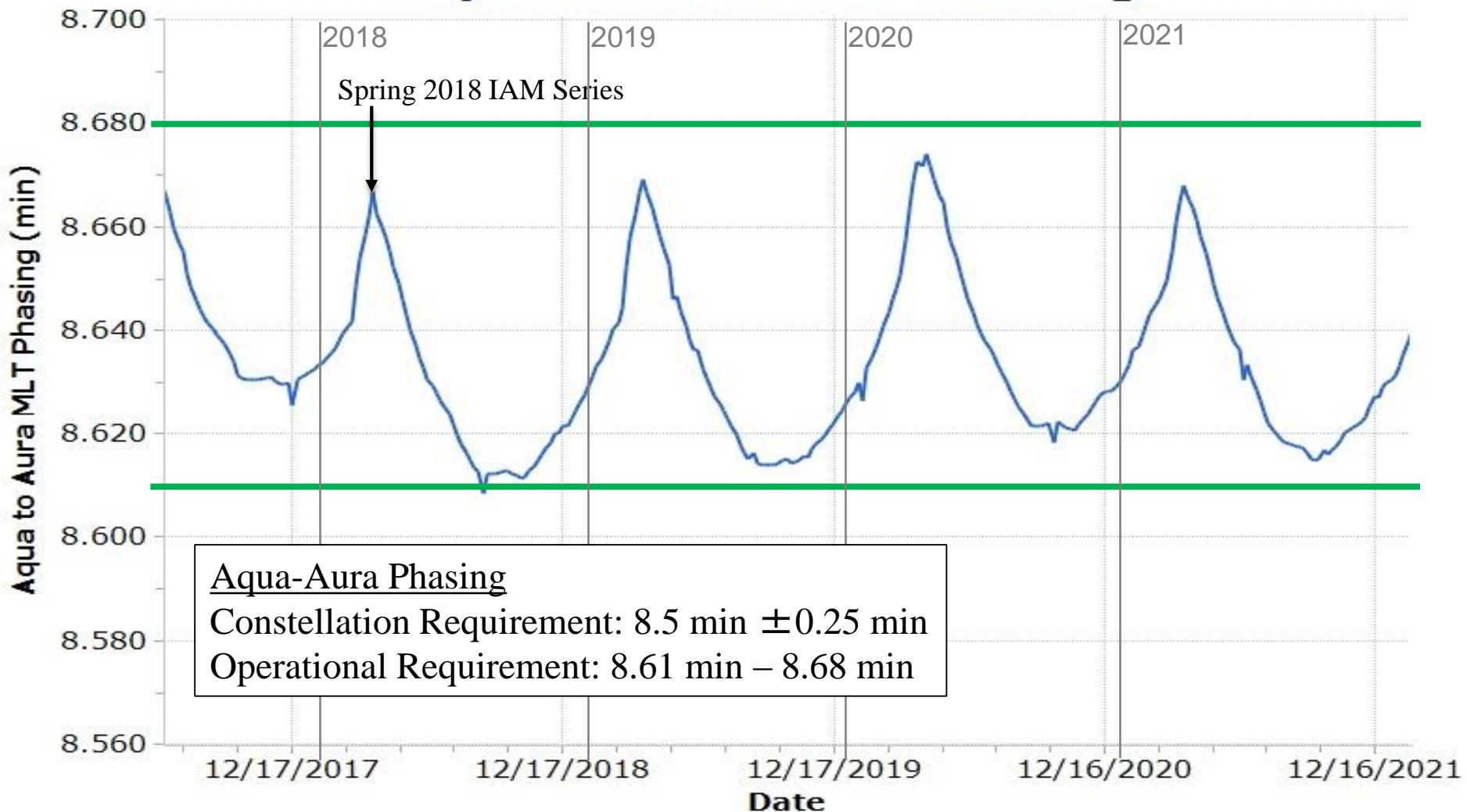
Aqua-Aura Lifetime MLT Phasing Based on Planned IAM Strategy

Aqua to Aura MLT Phasing



Aqua-Aura Lifetime MLT Phasing Based on Planned IAM Strategy

Aqua to Aura MLT Phasing



Aqua/Aura Spring 2017 Series Summary

- Aqua performed four inclination maneuvers between March 1st and March 29th
- Aura performed four inclination maneuvers between March 2nd and March 30th
- Aqua's second inclination maneuver performed differently from the first, even though both were planned with the same yaw angle
- Aqua's third inclination maneuver was re-planned based on the results and performance differences between the first two inclination maneuvers. The fourth and final inclination maneuver was re-planned based on the results from the third inclination maneuver
- Aura's final two inclination maneuvers were likewise re-planned to maintain the phasing with Aqua requirement
- Aqua's inclination maneuvers were between 0.1% and 1.3% cold
- Aura's inclination maneuvers were between 2% and 3% cold
 - Analysis being performed to update the Aura trending model and reduce these errors for the next IAM series

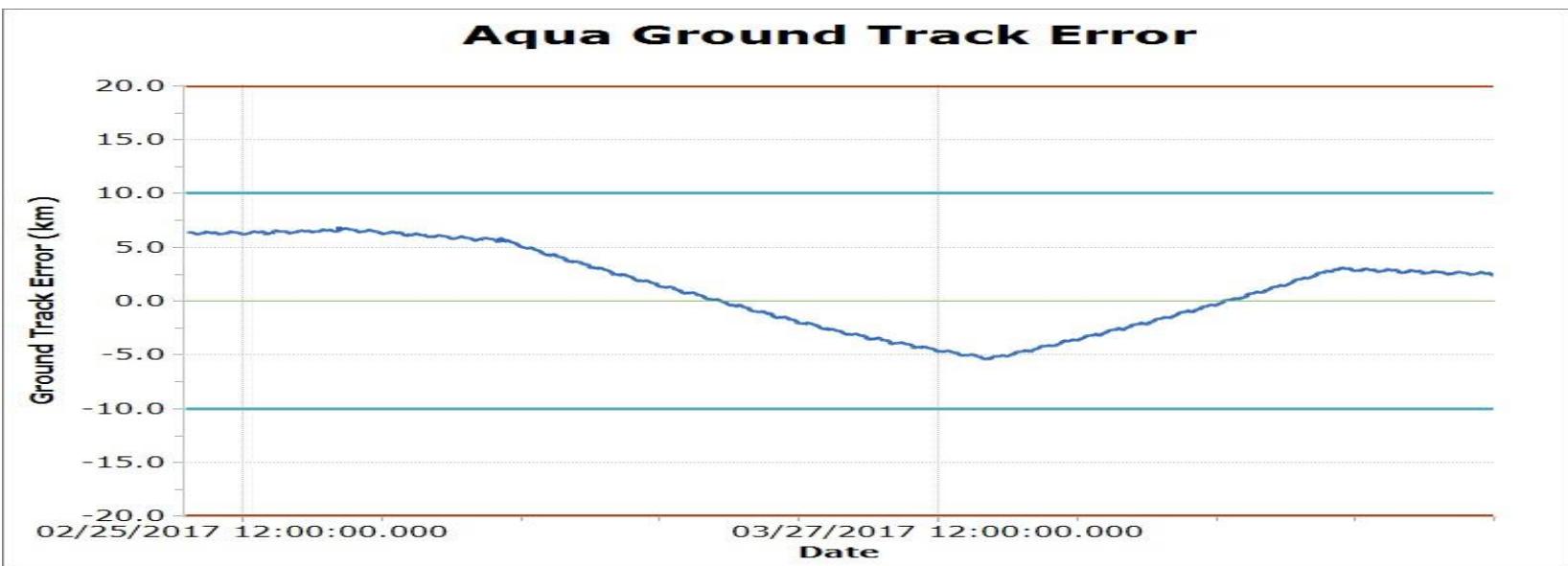
BACKUP SLIDES

Aqua Predicted vs. Definitive GTE Over The IAM Series

Predicted

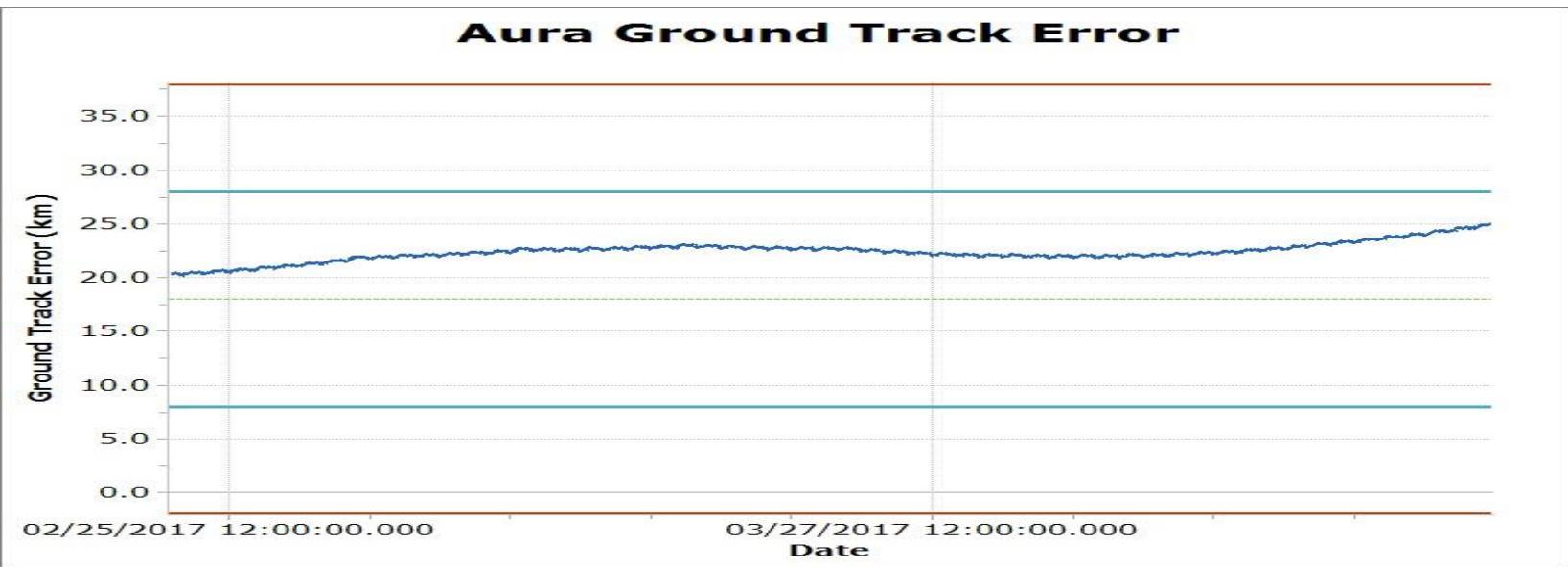


Definitive

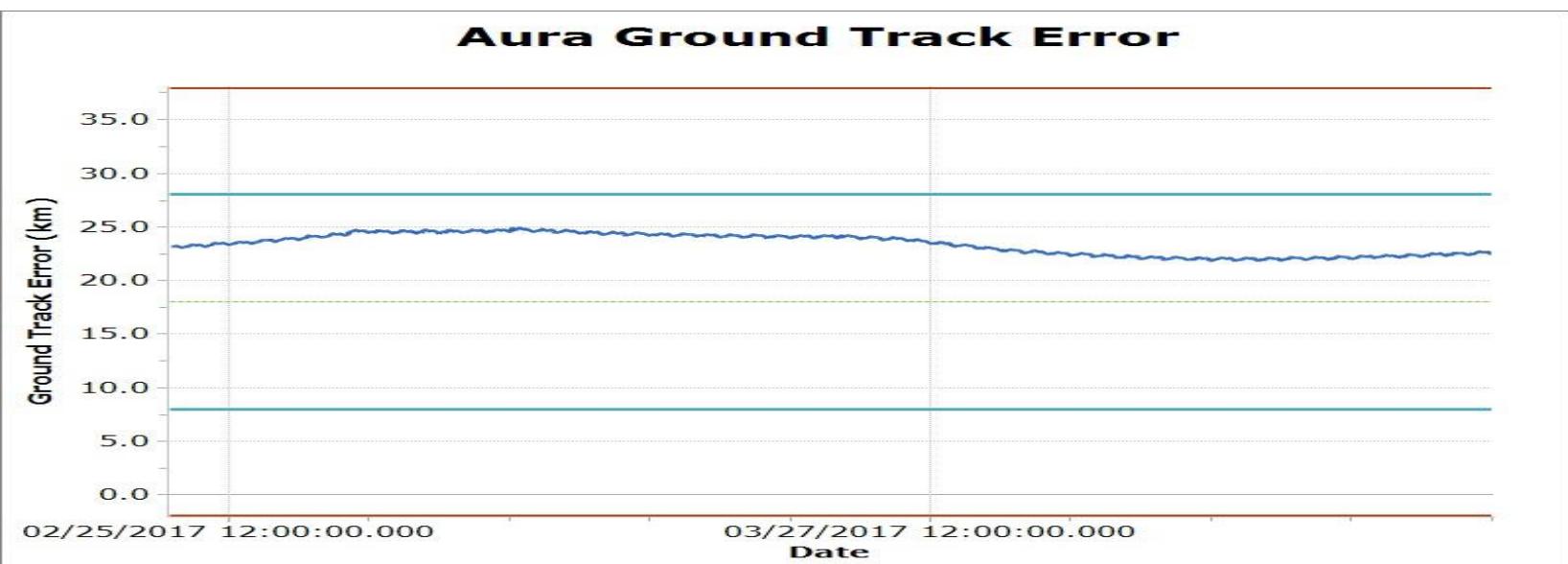


Aura Predicted vs. Definitive GTE Over The IAM Series

Predicted



Definitive



Aqua/Aura Mid-Series Planning Update

- **Aqua's achieved delta-SMA was much larger for IAM 53 vs. 52, even though both maneuvers were planned with similar inputs**
- **IAM 53 was planned using IAM 52's post-maneuver results since the maneuvers had the same yaw angle and were executed near the same orbit location.**
 - IAM 52 was planned using IAM 50's post-maneuver results due to IAM 50 having the closest yaw angle
- **IAM 53's performance was very different from IAM 52. The differences were attributed to the gyro-rate square wave significantly increasing the slew out and slew back thrust scale factors**
 - While SMA difference was larger than expected, it was still in family with previous maneuvers

Aqua/Aura Mid-Series Planning Update

- **IAM 54 and 55 yaw angles were updated due to IAM 53's performance and the large positive SMA effect on Aqua's ground track error**
 - Predicted IAM 54 and 55 using nominal large angle process
 - Used post-maneuver results from the most similar large angle IAM
 - Updated to larger yaw angle to generate negative SMA to correct ground track error induced by IAM 52 and 53
 - Set IAM 54 to -88.3 predicted (-90 commanded)
 - Used IAM 51's post-maneuver results to predict IAM 54 since IAM 51's yaw angle (-89.5 commanded) is the closest to IAM 54
 - Created backup plan to update IAM 55's angle based on IAM 54's performance
 - Predicted nominal yaw of -85.3 but could have been more negative if necessary
- **As a contingency analysis, analyzed ground track impact of IAM 54's performance being similar to IAM 53**
 - Could have used larger yaw angles to protect against adding positive SMA
 - Could have updated IAM 55 to use a larger yaw angle based on performance

Aqua/Aura Mid-Series Planning Update

- Below are the planning and post-maneuver values for IAM 52 and 53. Planned values are in darker blue, post-maneuver values are in lighter blue
 - Note that IAM 52's performance was cold in IAM due to a lower INC thrust scale factor (TSF). The angle off-set was greater than expected which, along with all TSF's being lower, caused the delta-SMA to be higher than expected
 - IAM 53's performance was hot in delta-SMA mainly due to significantly higher slew-out and slew-back TSFs

IAM #	Burn Time	Yaw	Slew Out TSF	INC TSF	Slew Back TSF	Delta-I (deg)	Delta-SMA (m)
52	13:43:54	-85.5	0.964	0.956	0.964	-0.008250	13.65
			0.937	0.965	0.937	-0.008168	18.85
53	13:50:57	-85.5	0.937	0.965	0.937	-0.008167	11.12
			0.986	0.960	0.986	-0.008157	52.30

Aqua/Aura Mid-Series Planning Update

- Below are the planning and post-maneuver values for IAM 54. Planned values are in darker blue, post-maneuver values are in lighter blue
 - IAM 54 was planned using the performance results from IAM 53
 - IAM 54's yaw angle increased to achieve a negative delta-SMA
 - The negative delta-SMA needed to maintain GTE requirements
 - Note that IAM 54's performance was cold in IAM due to a lower INC TSF. All TSF's being lower caused the delta-SMA to be higher than expected

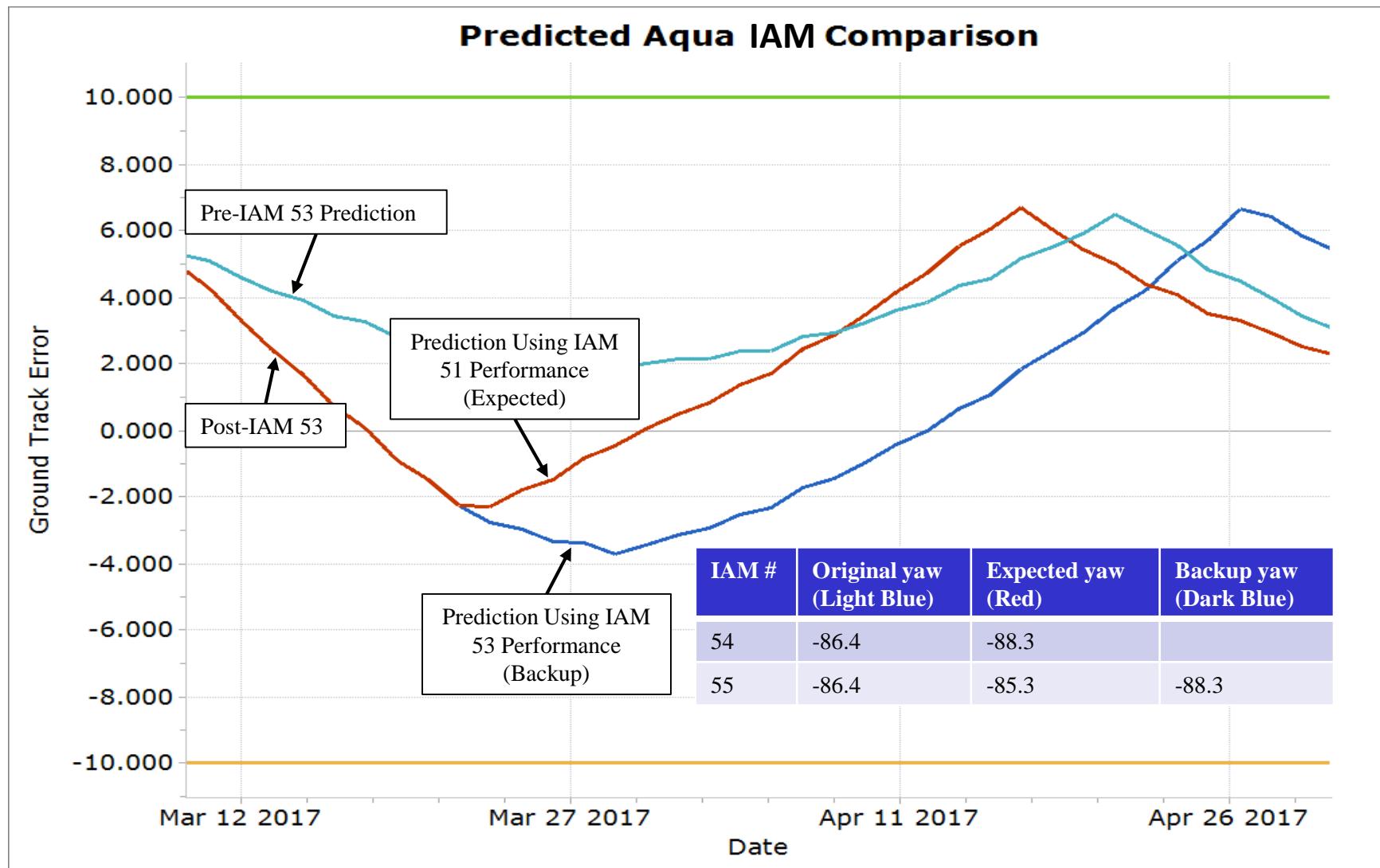
IAM #	Burn Time	Yaw	Slew Out TSF	INC TSF	Slew Back TSF	Delta-I (deg)	Delta-SMA (m)
54	15:44:11	-88.3	0.986	0.960	0.986	-0.008400	-105.00
			0.936	0.947	0.936	-0.008293	-23.75

Aqua/Aura Mid-Series Planning Update

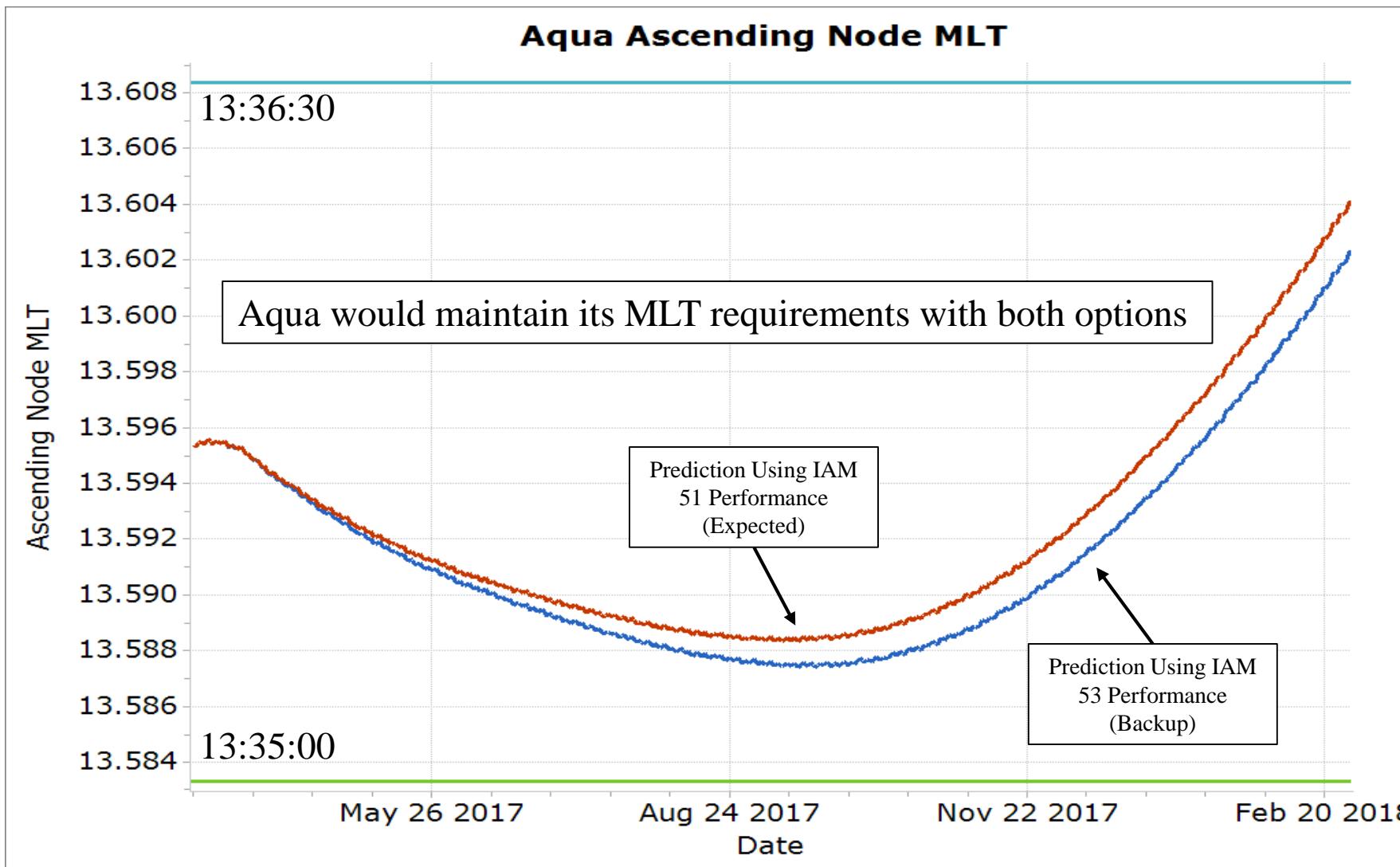
- Below are the planning and post-maneuver values for IAM 55. Planned values are in darker blue, post-maneuver values are in lighter blue
 - IAM 55 was planned using the performance results from IAM 54
 - IAM 55's yaw angle increased even more to achieve a larger negative delta-SMA
 - The negative delta-SMA needed to maintain GTE requirements

IAM #	Burn Time	Yaw	Slew Out TSF	INC TSF	Slew Back TSF	Delta-I (deg)	Delta-SMA (m)
55	15:51:17	-90.0	0.936	0.947	0.936	-0.008101	-99.10
			0.942	0.945	0.942	-0.008090	-107.90

Aqua/Aura Mid-Series Planning Update



Aqua/Aura Mid-Series Planning Update

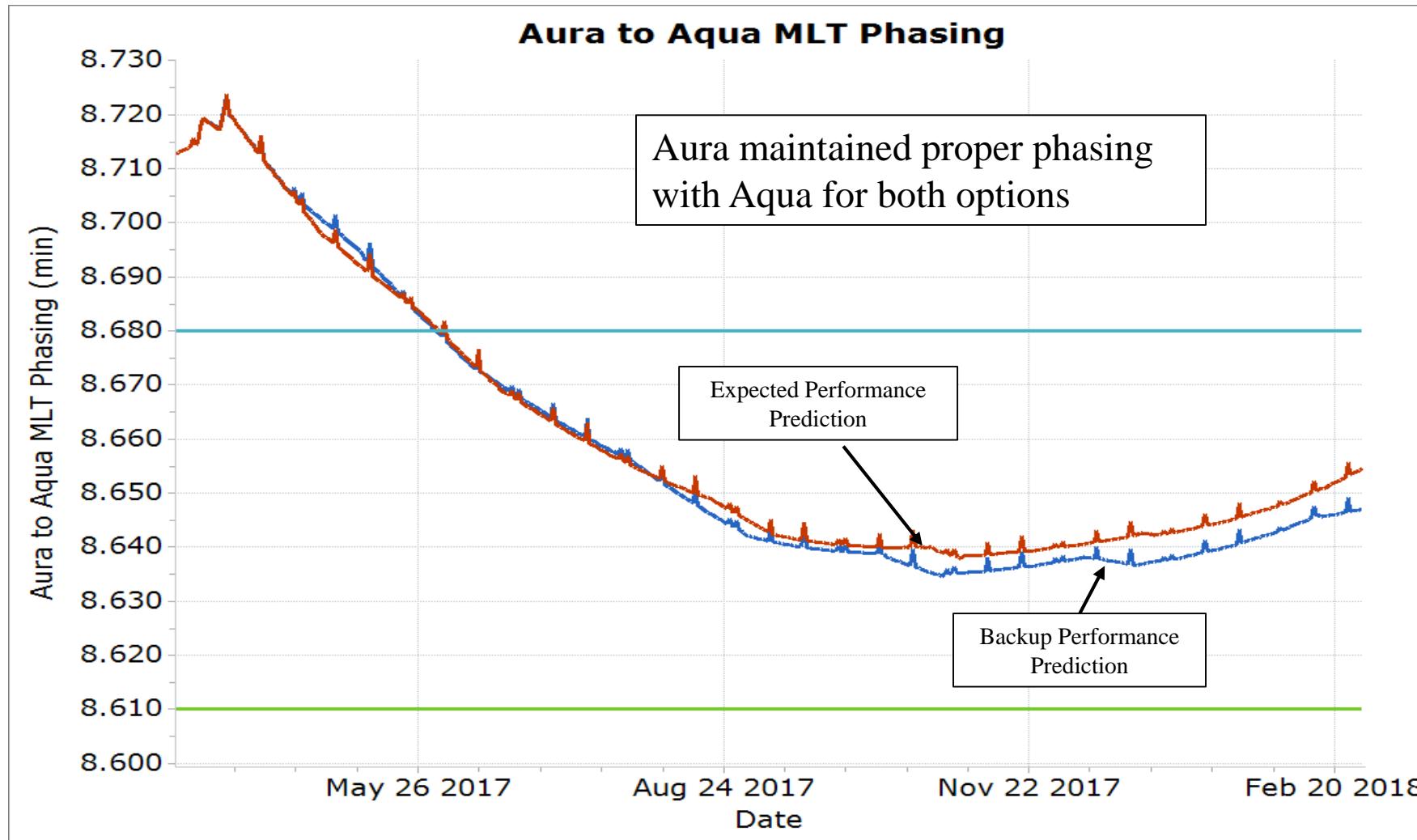


Aqua/Aura Mid-Series Planning Update

- **Due to Aqua's performance, it was necessary to update Aura's maneuvers to maintain the MLT phasing requirement**
- **Aura's burn durations were updated and the yaw angle for IAM 52 was updated**
 - Aura's IAM 51 burn duration updated due to Aqua's IAM 53 performance
 - Aura's IAM 52 burn duration updated due to Aqua's IAM 54 performance
 - Aura's IAM 52 yaw angle updated due to Aura RMM between IAM 51 and 52

IAM #	Original Plan		Replan	
	Duration (sec)	Yaw Angle (deg)	Duration (sec)	Yaw Angle (deg)
49	395	-83.80	395	-83.80
50	395	-83.80	395	-83.80
51	395	-83.80	405	-83.80
52	395	-83.80	410	-84.50

Aqua/Aura Mid-Series Planning Update



Aqua/Aura Mid-Series Planning Update

